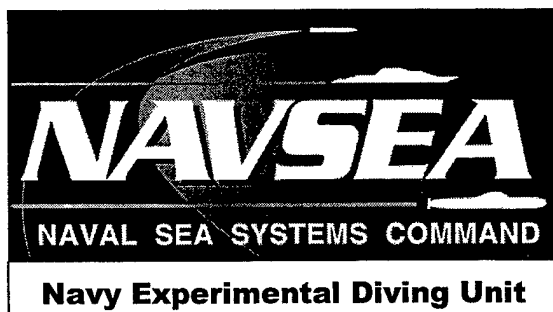


Navy Experimental Diving Unit  
321 Bullfinch Rd.  
Panama City, FL 32407-7015

TA 98-017  
NEDU TR 11-01  
October 2001

**ANU TESTING OF STEADFAST TECHNOLOGIES 15 VDC RESISTIVE  
HEATING SYSTEM (RHS)**



Distribution: Approved for public release; distribution is unlimited

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20020313 067

REPORT DOCUMENTATION PAGE					
1a. REPORT SECURITY CLASSIFICATION Unclassified		1b. RESTRICTIVE MARKINGS			
2a. SECURITY CLASSIFICATION AUTHORITY		3. DISTRIBUTION/AVAILABILITY OF REPORT  DISTRIBUTION STATEMENT A: Approved for public release; distribution is unlimited			
2b. DECLASSIFICATION/DOWNGRADING AUTHORITY					
4. PERFORMING ORGANIZATION REPORT NUMBER(S) NEDU Technical Report No. 11-01		5. MONITORING ORGANIZATION REPORT NUMBER(S)			
6a. NAME OF PERFORMING ORGANIZATION Navy Experimental Diving Unit	6b. OFFICE SYMBOL (If Applicable) 03	7a. NAME OF MONITORING ORGANIZATION			
6c. ADDRESS (City, State, and ZIP Code) 321 Bullfinch Road, Panama City, FL 32407-7015		7b. ADDRESS (City, State, and Zip Code)			
8a. NAME OF FUNDING SPONSORING ORGANIZATION Naval Sea Systems Command	8b. OFFICE SYMBOL (If Applicable) 00C	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER			
8c. ADDRESS (City, State, and ZIP Code)  2531 Jefferson Davis Highway, Arlington, VA 22242-5160		10. SOURCE OF FUNDING NUMBERS			
		PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO. TA 98-017	
11. TITLE (Include Security Classification) (U) ANU Testing of Steadfast Technologies 15 VDC Resistive Heating System (RHS) Dry Suit Liner.					
12. PERSONAL AUTHOR(S) BMCS (DSW/SS/SW) Charles H. Neste. and Ken E. Fredrickson.					
13a. TYPE OF REPORT Final Technical Report	13b. TIME COVERED FROM <u>Sept 98</u> TO <u>Aug 01</u>	14. DATE OF REPORT (Year, Month, Day) 01 Aug 30		15. PAGE COUNT 22	
16. SUPPLEMENTARY NOTATION					
17. COSATI CODES		18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)			
FIELD	GROUP				SUB-GROUP
19. ABSTRACT (Continue on reverse if necessary and identify by block number) This test represents an effort toward developing, evaluating and recommending for ANU listing an electrically powered resistive heating system (RHS) to provide Special Warfare divers with adjunct thermal protection while conducting SDV operations. Formerly known as the EXOTEMP and Active Thermal Protection System (ATPS), the RHS is being developed and manufactured by Steadfast Technologies (Brandon, FL).					
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT  <input type="checkbox"/> UNCLASSIFIED/UNLIMITED <input checked="" type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION  Unclassified		
22a. NAME OF RESPONSIBLE INDIVIDUAL NEDU Librarian	22b. TELEPHONE (Include Area Code) 850-230-3100		22c. OFFICE SYMBOL		

The RHS dry suit liner-long-sleeved body suit with integral socks is made of a thin, stretchy knit fabric. The entire suit has electric resistance tinsel wires stitched to it in patterns that course along the longitudes of the trunk, arms, and legs and cover the tops of the feet. Five-finger electric gloves that plug into an outlet at the end of each sleeve have wires stitched to them on both sides of the hand and the backs of the fingers.

Power output to the suit is regulated via voltage sensing circuitry that measures battery voltage and regulates the power output duty cycle to deliver approximately 270 watts of heat to the diver. Electrical protection, conforming to AODC 035 specifications, is provided by Ground Fault Interrupter (GFI) circuitry.

The function of the voltage controller was evaluated by measuring the power delivered to the suit. The RHS delivered 272.6 watts, 278.9 watts, and 259.5 watts at 12, 15, and 19.5 volts, respectively. The GFI was tested to determine the time required to detect a fault, the voltage or current it required to constitute a fault, as well as the overall reliability of its circuitry at 12, 15, and 19.5 volts. The average time needed to detect a fault was 2.39, 2.45, and 2.62 milliseconds at 12, 15, and 19.5 volts, respectively. The average current required to constitute a fault was 0.71, 0.92, and 1.20 milliamps at 12, 15, and 19.5 volts. Both average trip time and current were well below the 30mA and 20ms allowed by AODC standards. The reliability of the GFI circuitry was determined by inducing a fault 1,000 times at 3 different voltages and observing the response. Allowing zero failures, testing results showed a reliability of 99.5% with a 99% confidence level.

All pressure vessels were hydrostatically tested to P9290 standards with satisfactory results. Electrical cabling was tested for continuity, dielectric withstanding voltage, and hydrostatic and insulation resistance in accordance with standard SDV practices, and results were satisfactory. The system underwent environmental testing to determine if it would withstand the rigors of routine shipping and handling. The environmental testing consisted of mechanical shock testing of  $40 \pm 5g$  for 15 to 20 milliseconds and random vibration of 8g root-mean-square (RMS) from 20 to 2,000 Hz. For 72 hours low- and high-storage temperature testing was conducted at  $-40^{\circ}F$  ( $-40^{\circ}C$ ) and  $160^{\circ}F$  ( $71.1^{\circ}C$ ), respectively. Thermal shock testing varied the temperature between  $-65^{\circ}F$  ( $-53.9^{\circ}C$ ) and  $70^{\circ}F$  ( $21.1^{\circ}C$ ). Satisfactory operation was verified after each separate test.

In-water tests were conducted in both a test pool and open water. Test pool dives using a complete MK VIII SDV were conducted to determine that operators were able to perform emergence egress and operate all controls. Divers wore dry suits and then wet suits over the RHS undergarment while they used MK 16 and MK 25 UBAs and open circuit scuba. Open water dives were conducted to simulate full mission profiles; however, due to poor fit of available dry suits, only wet suits were used for the open water testing. Again, MK 16 and MK 25 UBAs and open circuit scuba were used in open water. The RHS did not impede diver performance and did provide adequate adjunctive thermal protection to the divers. Therefore, ANU listing of the RHS system for SDV operations is recommended.

## CONTENTS

	<u>Page No.</u>
Introduction.....	1
Methods.....	2
Subjects.....	2
Equipment and Instrumentation.....	3
Apparatus .....	3
Procedures .....	5
Functional and Electrical Safety Testing.....	5
Environmental Testing .....	5
In Water Testing .....	5
Results.....	5
Suit Power .....	5
GFI Trip Time .....	6
GFI Trip Voltage/Current .....	7
GFI Reliability .....	7
Cable Tests .....	8
Continuity Tests .....	8
Dielectric Withstanding Voltage .....	8
Hydrostatic Tests .....	8
Insulation Resistance.....	8
Vacuum and External Pressure Testing of the Battery Canisters and Control Boxes.....	8
In-Water Testing .....	9
Discussion .....	10
Conclusions .....	12
Recommendations.....	12
References .....	13
Appendix A - Steadfast Technologies Resistive Heating System (RHS) Operation and Maintenance Manual .....	A1-A4

## ILLUSTRATIONS

<u>Figure No.</u>	<u>Page No.</u>
1. RHS suit, control box, cable and battery can.....	1
2. Wet suit with pass-through cable and control box .....	2
3. Diver in wet suit with MK 16 .....	3
4. Diver in wet suit with MK 25 .....	3
5. Diver in dry suit with MK 25.....	3
6. Diver in dry suit with Scuba .....	4
7. Battery can, cable and control box .....	4
8. GFI trip time graph .....	6
9. GFI trip voltage/current.....	7
10. RHS glove power lead.....	9
11. Dry suit wrist seal .....	9
12. MK VIII SDV with RHS battery can and control box .....	10

## Tables

1. GFI trip time .....	6
2. GFI trip current .....	7

## INTRODUCTION

In support of Naval Sea Systems Command (NAVSEA) Task 98-017, Navy Experimental Diving Unit (NEDU) conducted a technical and operational evaluation of the Resistive Heating System (RHS), manufactured by Steadfast Technologies of Brandon, Florida. Testing of the RHS consisted of functional and electrical safety testing, environmental testing and operational evaluations.

The RHS is intended to provide Naval Special Warfare divers with adjunctive thermal protection while they are wearing wet or dry suits during SDV operations.

The Steadfast electric RHS consists of a 12-foot umbilical cable, a controller, a pass-through cable, an electric suit, electric gloves, and an electrode worn on the diver's skin. It is powered by a dedicated battery pack consisting of standard MK 89 cells arranged in a 15-volt, 300 amp hour (Ah) configuration (see Figure 1). The system must meet the full requirements of the Association of Offshore Diving Contractors (AODC 035) Code of Practice for the Safe Use of Electricity Underwater. The U.S. Navy has adopted the AODC Code for diver heating.

The RHS dry suit liner-a long-sleeved body suit with integral socks-is made of a thin, stretchy knit fabric. The entire suit has shielded tinsel™ wires stitched to it in patterns that course along the longitudes of the trunk, arms, and legs and cover the tops of the feet. Five finger gloves that plug into the outlet at the end of each sleeve have wires stitched to them on both sides of the hand and on the backs of the fingers.

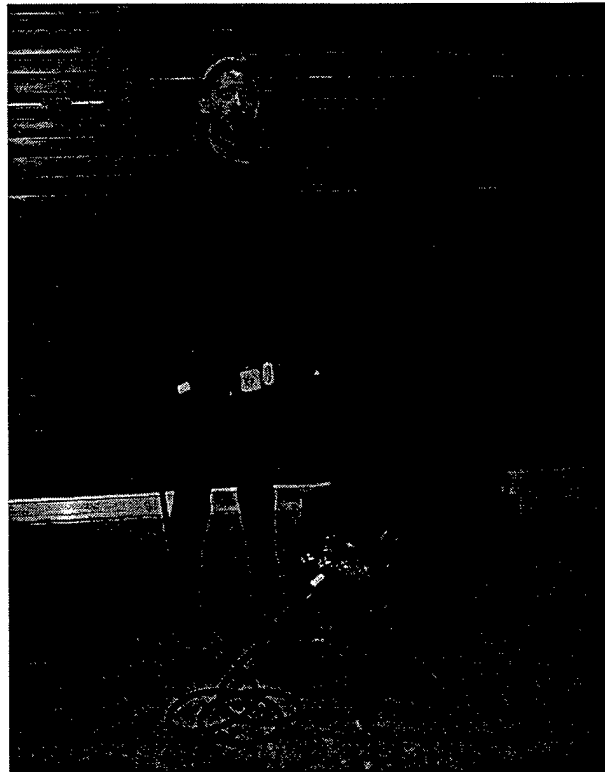
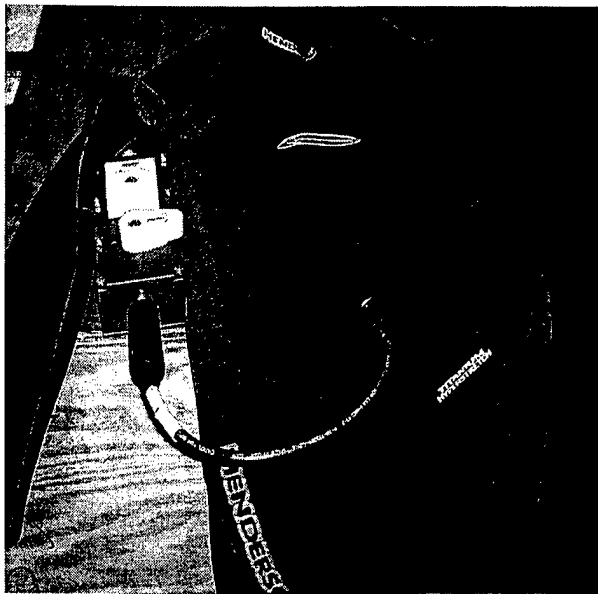


Figure 1. RHS suit, control box, cable and battery can

The controller incorporates a ground fault interrupter (GFI) that trips in less than 5 milliseconds when the current from the power supply to the shield wire, or through the water exceeds approximately 1 milliamper (mA). The electrode connects the diver's body to the shield wire ensuring the skin potential and the shield are electrically connected (not relying on conductance through seawater).



**Figure 2.** Wet suit with pass through cable and control box

Finally, the connection between the controller and the pass-through cable has no locking arrangement and may be disconnected with a straight pull (see Figure 2).

The controller incorporates a manual on-off switch, the GFI circuitry, a GFI override switch, and indicating lights. Nuisance trips, commonly caused by a faulty underwater connector may be overridden when the diver judges that the danger from loss of heat is greater than the potential electrical hazard. The controller also incorporates an "auto-latch" feature, that probes the circuit twice a minute and applies power if it senses that a suit is connected. The auto-latch feature helps to reduce the effect of nuisance trips.

The controller applies power to the suit in pulses. Internal circuitry senses the voltage being supplied and adjusts the pulse to result in a fixed average heating rate of 260 watts, 11 of which are delivered to each hand.

## METHODS

Testing of the RHS, per reference 2, was divided into three phases: functional and electrical safety testing, environmental testing, and in-water testing. First, GFI functional and performance testing was conducted. This included evaluating the performance and reliability for each of the GFIs. This test included trip time, trip current, relatch and reliability. Also, all housings were hydrostatically tested, and all cables were tested to ensure safe performance during in-water testing. After functional testing was successfully completed, the in-water to ensure evaluation phase was conducted. This included dives in a test pool and open water that SDV operators could safely operate all required boat controls as well as egress the boat in case of an emergency. Then environmental testing was conducted to ensure that the RHS would meet the rigors of routine shipping and handling. This phase included mechanical shock, vibration, low- and high-temperature storage and thermal shock testing.

## SUBJECTS

Eight volunteer Navy-qualified divers completed the test dives under this study.

## EQUIPMENT AND INSTRUMENTATION

### Apparatus

Diving suits. The RHS was dove with Viking (Trelleborg Viking, Inc., Portsmouth, NH) Pro 1000 Surveyor dry suits, M-400 Thinsulate® liners, and wet suits appropriate for the test pool water temperature.

### Underwater breathing apparatus.

Test dives were conducted in operational MK 16s, MK 25s and open circuit scuba (see Figures 3 through 6).



Figure 3. Diver in wet suit with MK-16



Figure 4. Diver in wet suit with MK-25

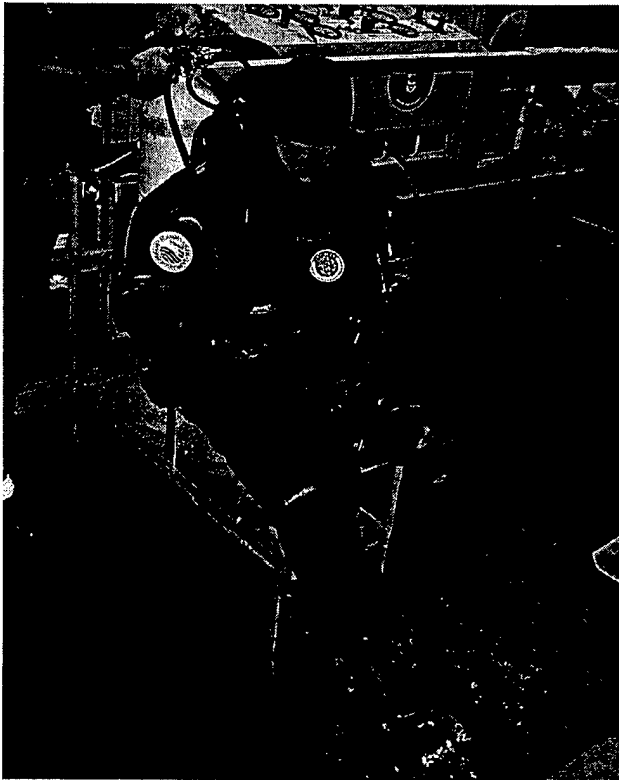
SDV. A MK VIII SDV, complete with top skins and forward and aft hatches, was placed at the bottom of the test pool for divers to conduct emergency egress procedures and operated in open water to simulate an operational scenario.

Test pool. Manned testing was conducted at a 15-foot depth test pool with the water temperature maintained between 40 °F and 55 °F (4.4 °C and 12.8 °C). The test pool water temperature was monitored with a YSI 701 thermistor situated near the divers and was noted in the dive log at the beginning and end of each dive.



Figure 5. Diver in dry suit in MK 25



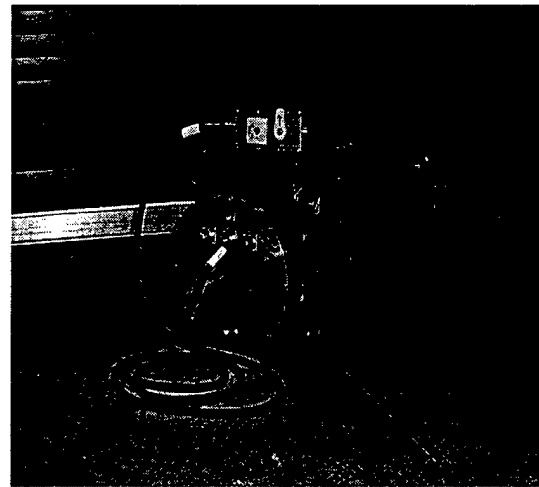


**Figure 6.** Diver in dry suit with scuba

Power supply. The RHS is powered by a 15-VDC power source of MK 89 cells housed in a Coastal Systems Station (CSS) fabricated battery can and equipped with underwater cables and power connectors (see Figure 7).

Ground Fault Interrupter. All cables from the GFI to the diver and all garment-heating wires are shielded and tied to a common ground (the GFI case) and coupled to the diver via a seawater path. Due to variability of resistance through the seawater path, a skin electrode is used to maintain a known resistance value in the grounding circuit. Each diver's GFI connects this grounding system to the negative power source terminal through a large resistor, so that the water, the wire shields, and the diver's body are weakly held at 0.0 volts with respect to the power source.

The GFI is intended to provide electrical protection. If the wire insulation or connector seal integrity is compromised, any exposure of the water, a diver's skin, or a conductor to the shield wire at more than 3.5 volts potential raises the voltage on the grounding system above the trip level. Each GFI must trip at less than 30 mA with a response time of less than 20 ms, as per reference (1).



**Figure 7.** Battery can, cable and control box

## PROCEDURES

### Functional and Electrical Safety Testing

Four controllers containing the GFI and voltage controller circuitry were tested per reference (2), to determine whether the GFI provided electrical protection within guidelines specified in reference (3) and whether the power output to the diver complied with recommendations in reference (4). In this series of tests the trip time, trip current, and suit power of each of the four controllers was measured at three voltages: 12, 19.5, and the nominal voltage of 15 VDC.

### Environmental Testing

The system underwent environmental testing to determine if it would withstand the rigors of routine shipping and handling. This testing consisted of mechanical shock testing of  $40 \pm 5$  g for 15 to 20 msec and random vibration of 8 g RMS from 20 to 2,000 hertz (Hz). Low- and high-storage temperature testing was conducted at  $-40$  °F and  $160$  °F ( $-40$ °C and  $71.1$ °C) respectively, for a period of 72 hours. Thermal shock testing varied the temperature between  $-65$  °F and  $70$  °F ( $-53.9$ °C and  $21.1$ °C). Satisfactory operation of the system was verified after each separate test.

### In-Water Testing

In-water tests were conducted both in a test pool and open water. Test pool dives using a complete MK VIII SDV were conducted to determine that operators could perform emergency egress procedures and operate all controls. While using MK 16 and MK 25 UBAs and open circuit scuba, divers wore dry suits and then wet suits over their RHS undergarments. Open water dives were conducted to simulate full mission profiles; however, because the available dry suits fit poorly, only wet suits were used for the open water portion of testing. Again, MK 16 and MK 25 UBAs as well as open circuit scuba were used in open water. Results showed that the RHS did not impede diver performance and did provide adequate adjunctive thermal protection to the divers.

## RESULTS

### Suit Power

The suit power was measured at three discrete voltage levels: 12, 15 and 19.5 volts. Voltage drops across cabling were accounted for by measuring voltage directly at the suit end of the pass through cable. Current was measured directly across a 100 millivolt per 100 amp shunt resistor in series with the power supply output. The power at each voltage level was calculated using Ohm's law.

$$\text{Power} = V \times I^2$$

## Suit Power

Power supply voltage (VDC)	Suit power (Watts)
12.0	272.6
15.0	278.9
19.5	259.5

The lower power output 19.5 volts as to compared to 12 and 15 volts is a result of the voltage controlling circuit. The voltage controller operates on a duty cycle resulting a pulsed power output. The pulse width of the output is inversely proportional to battery voltage. At 12 volts, the output is continuously on. The output begins to pulse at slightly above 12 volts and continues to shorten pulse width as battery increases. The purpose of this circuit is to insure that the total power delivered to the suit is below the threshold where burns can occur.

## GFI Trip Time

Each of the four GFI/controllers was tested at 12, 15, and 19.5 volts. A fault was induced, and the response of the GFI to the fault was recorded. For each tracing, channel 1 recorded the suit voltage and channel 2 the voltage on the shield, as seen in Figure 8.

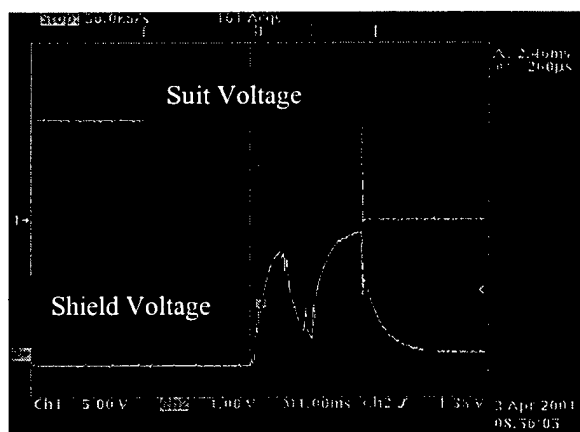


Figure 8. GFI Trip Time Graph

Table 1. GFI Trip Time

	Trip Time @ 12V (msec)	Trip Time @ 15V (msec)	Trip Time @ 19.5V (msec)
GFI S/N 1720	2.46	2.26	3.04
GFI S/N 1721	2.46	2.76	2.84
GFI S/N 1722	2.20	2.22	2.10
GFI S/N 1723	2.44	2.56	2.52

All of the GFIs at each voltage showed trip response times well within AODC guidelines of 20 msec as seen in Table 1.

### GFI Trip Voltage/Current

The current required to trip the GFI was determined in accordance with NEDU Standard Test Plan 99-27, Annex B, section 5.3. In each case, voltage on the shield was increased until a trip was detected and this voltage, on the shield, was recorded. An oscilloscope trace showing the trip point was recorded for each of the GFIs at voltages of 12, 15, and 19.5. (see figure 9). The internal resistance of each GFI was measured, and then using Ohm's law the GFI trip current was calculated as:

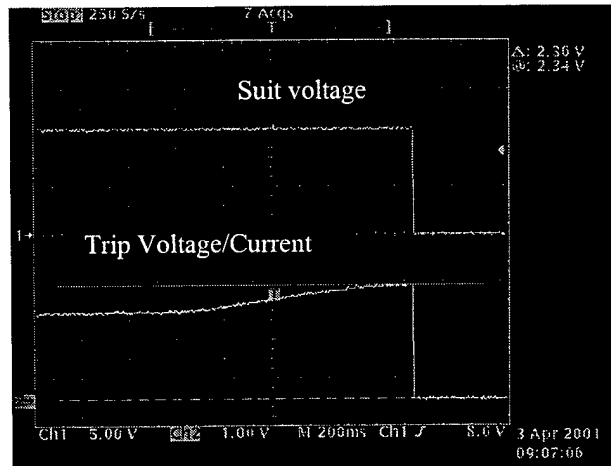


Figure 9. GFI Trip Voltage/Current

$$I_{\text{trip}} = V_{\text{shield}} / R_{\text{gfi}}$$

**Table 2.** GFI Trip Current

	Trip Current @ 12v (mA)	Trip Current @ 15v (mA)	Trip Current @ 19.5v (mA)
GFI S/N 1720	0.682	0.919	1.156
GFI S/N 1721	0.802	1.040	1.390
GFI S/N 1722	0.665	0.857	1.122
GFI S/N 1723	0.682	0.863	1.147

All of the trip currents are significantly below the 30 mA fault current allowed by reference (3).

### GFI Reliability

To test the reliability of the GFIs, a fault was induced 1,000 times and the GFI responses were observed. Zero failures through the 1,000 cycles resulted in a better than 99.5% reliability with a 99% confidence level. All four GFIs completed 1,000 cycles at 12, 15, and 19.5 volts without failure. A failure would have been a response outside the allowable 30 mA current and the 20 ms time specified by reference (3). All GFIs completed 3,000 trip and relatch cycles without failure.

## Cable Tests

All RHS cable assemblies were tested in accordance with NEDU Standard Test Plan 99-27 that incorporated standard SDV cable test procedures.

### Continuity Tests

Continuity testing required a pin-to-pin resistance of less than 0.05 ohms. This test indicated the quality of the electrical contact of the wire to the pin in each connector. In all cases the resistance through the cable, pin to pin, was less than 0.05 ohms.

### Dielectric Withstanding Voltage

The dielectric withstanding voltage test was conducted to determine how well each wire within the cable was insulated and to determine if any defects were in the connectors, cable manufacture, or assembly. All cables were tested with 1,350 volts AC on a conductor for at least one minute and less than 1 mA of leakage current to any other conductor was measured.

### Hydrostatic Tests

Hydrostatic testing of the cables was conducted to determine if the cable insulation, the potting of connectors, and the potting to cable insulation bond were sound. This test was conducted by submerging each cable, except for the ends, in fresh water and conducting ten cycles to the pressure of 135 psig. The first nine cycles were held for ten minutes and the tenth was held for one hour.

### Insulation Resistance

Insulation of the cables was tested to ensure that the resistance between conductors remained greater than 100 megohms while submerged.

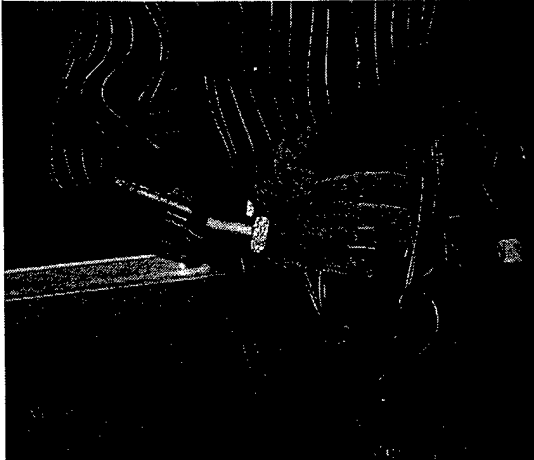
All cables used with the RHS, four controller cables and four pass-through cables, were tested and found to be satisfactory. The only discrepancy noted was that the manufacturer must permanently identify each cable with part numbers and serial numbers to facilitate record keeping of testing. This had not been done, so the cables were identified with tags at the testing facility.

## Vacuum and External Pressure Testing of the Battery Canisters and Control Boxes

All pressure vessels, two battery canisters and four control boxes, were hydrostatically tested in accordance with reference (8). Testing was to ensure structural and watertight integrity and it included a vacuum test of the battery canisters and a series of ten cycles to a pressure of 135 psig. The vacuum test was omitted on the control boxes, as no vacuum fitting was provided. The housings were held at pressure for ten minutes for the first nine cycles and for one hour on the tenth cycle. All housings showed no signs

of water intrusion or structural deformation; therefore, all hydrostatic testing was considered satisfactory.

### In-Water Testing



**Figure 10.** RHS Glove Power Lead

In-water tests were conducted in both a test pool and open water in accordance with reference (2), annexes G and I. Test pool dives using a complete MK VIII SDV were conducted to verify that operators were able to perform emergency egress procedures from forward and aft compartments within ten seconds and to operate all controls in simulated at-sea conditions. The SDV's ballast, trim and air subsystems were fully functional, and the topskins and canopies were completely installed. Two of the canopies eventually were broken at the hinges and would not operate in their normal condition; however, the canopies were put in place and used during the simulated egress procedures. The air subsystem required

a charge of at least 1,500 psig and was maintained at this pressure throughout all tests. Divers used MK 16, MK 25 UBAs and open circuit scuba, to complete 16 manned dives. 10 dives were conducted wearing dry suits over the RHS and six dives were conducted wearing wet suits over the RHS.

Divers wearing dry suits encountered minor leaks, primarily from the wrist seals. This was attributed to the fact that the seals had previously been cut and the dry suits fit poorly. The power lead for the gloves also contributed to the potential for leaks at the wrist seal. (See Figures 10 and 11 for views of the power lead for the glove and dry suit wrist seal, respectively.) Even with the reduced mobility caused by the dry suits, divers were able to perform emergency egress from the SDV and to operate all controls.

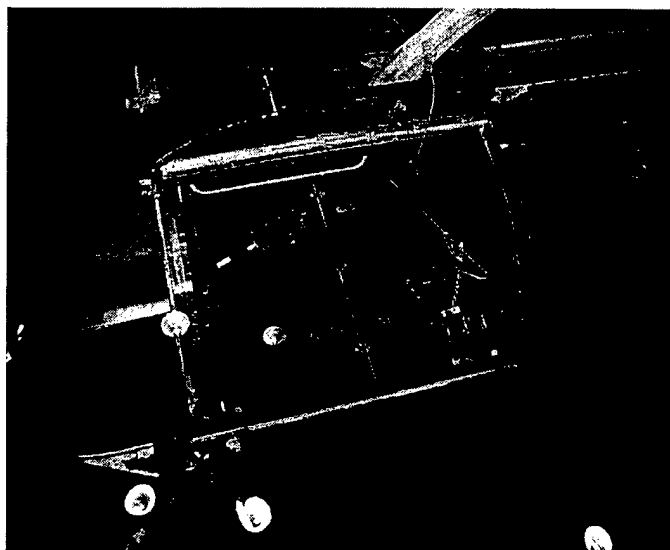


**Figure 11.** Dry suit wrist seal

Having the battery can in the forward compartment forced the pilot and navigator wearing MK 16 UBAs too far forward to be able to operate boat controls conveniently. (See figure 12.) However, even with these minor difficulties the diver's emergency egress and SDV operation while wearing dry suits was satisfactory.

The divers reported that their test pool dives with wet suits were much more comfortable compared to dry suits. The RHS suit liner did not cause any restriction in their mobility, and all of the test divers regarded it as a comfortable, adequate source of adjunctive thermal protection. Again having the battery can in the forward compartment impeded divers using MK 16 UBAs.

Due to the reduced mobility divers experienced with Viking dry suits in the test pool, open water dives were conducted in wet suits only. Again the operators used MK 16 and MK 25 UBAs and open circuit scuba while they performed all required boat procedures.



**Figure 12.** MK VIII SDV with RHS battery can and control box

Open water dives were conducted to simulate full mission profiles. To verify that the RHS did not interfere with SDV control systems, the SDV pilot and copilot wore the RHS while operating the vehicle and its subsystems. With the RHS energized, all of the SDV subsystems, including navigation, control and propulsion performed satisfactorily through the full mission duration. At the time of the test, the SDV and all SDV subsystems were fully operational, and, unimpeded by the RHS battery cans or cabling, the operators were able to operate the vehicle and its subsystems. Again, MK 16 and MK 25 UBAs and open circuit scuba were used. Divers reported that the RHS did not impede their performance and provided more than adequate adjunctive thermal protection during test pool phase 40°F (4.4°C) and open water 62°F (16.7°C).

## **DISCUSSION**

The RHS system well exceeded all requirements of reference (3) for the safe use of electricity in an underwater environment. Environmental testing provided the data to suggest that the RHS system could withstand the rigors of routine shipping and handling. However, during environmental testing at -65°F (-53.9°C) the RHS controller/GFI (Steadfast Part# 1202, Serial #1721) was unintentionally dropped onto concrete from a height of approximately 4 feet. This mishap was clearly outside the test protocol, but two failures were noted afterward. First, the voltage controller did not function as designed. The duty cycle feature, which controls the power output, failed and allowed uninterrupted power to be delivered to the suit. Second, the GFI failed to function at all. To verify that the failure resulted from the mishap and not thermal shock,

two additional GFI control boxes were retested for thermal shock per reference (2) Annex E and were found to function properly.

As NEDU, the vendor, and the circuit designer agreed, a postmortem was conducted on the GFI/controller to determine the cause of this dual failure. The findings are as follows:

- a) All mechanical seals were intact. The integrity and function of the housing and connectors were not compromised.
- b) Three of the four nylon mounting screws were sheared off. The fourth was simply not connected.
- c) One of the six MOSFET output transistors was shorted (normal failure mode). The remaining five tested satisfactory. The shorted MOSFET was quite obvious from signs of significant overheating.
- d) One integrated circuit on the GFI board failed. This was also a visible failure.

The impact to the RHS at an extremely low temperature obviously induced all three observed failures. Integrated circuits are made to operate at low temperatures (-65°F / 53.9°C); however, such components are simply unable to withstand significant mechanical shock at these temperatures. Component failures such as those observed must be anticipated, although no feasible method of design can mitigate them. The brass hardware used to connect the GFI and controller circuit boards was intact; therefore, the vendor is currently replacing all nylon mounting screws with brass ones in the control boxes. This will be standard practice in the future. The brass screws will have no effect on the electronic function of the circuit boards and will provide improved mechanical mounting; therefore, we believe that this corrective action is acceptable.

Failures such as the one that resulted from dropping the RHS system could occur during shipment, but such damages would be observed during pre dive checks and would not jeopardize in-water safety.

During the test pool phase of the in-water evaluation, the divers' mobility was reduced while they were wearing dry suits. This problem was amplified by the location of the battery can in the forward compartment, especially while the divers were wearing MK 16 UBAs. Numerous leaks in the dry suit were encountered, primarily due to wrist and neck seals that had previously been cut down and poor fitting suits. Therefore divers decided to dive in open water with only wet suits.



## CONCLUSIONS

The RHS met or exceeded all test criteria prescribed in reference (2). It can provide safe, reliable adjunctive thermal protection to Naval Special Warfare divers conducting SDV operations.

## RECOMMENDATIONS

Based on the testing reported in enclosure (1) and reference (2), we recommend including the Steadfast Diver Electric Resistive Heating System (RHS) on the Authorized for Navy Use list [reference (10)], as Category II equipment listed in section 002, paragraph 2.3 Diver Heating Equipment:

CAT II 2.3.15	RESISTIVE HEATING SYSTEM	STEADFAST TECHNOLOGIES	VARIOUS	APPROVED FOR SDV USE ONLY. APPROVED FOR USE WITH WET OR DRY SUITS. GENERAL NOTES (1) AND (2) OF SECTION 2.2 APPLY WHEN USED WITH VVDS.
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All future RHS cables must be permanently marked by the manufacture to include part number and serial number.

## REFERENCES

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## **APPENDIX A**

### **STEADFAST TECHNOLOGIES RESISTIVE HEATING SYSTEM (RHS) OPERATION AND MAINTENANCE MANUAL**

#### **Instructions for Steadfast Diver Electric Resistive Heating System (RHS)**

#### **15 Volt Controllers, Electric Suits, Gloves, Electrodes, and Passthrough Assemblies**

### **SYSTEM DESCRIPTION**

The Steadfast electric resistive heating system consists of a 12 foot umbilical cable, a controller, a passthrough cable, an electric suit, and electric gloves, and an electrode worn on the diver's skin. The system meets the full requirements of the Association of Offshore Diving Contractors (AODC) Code of Practice for the Safe Use of Electricity Underwater. The US Navy has adopted the AODC Code for diver heating. The garments incorporate a grounded shield wire. The controller incorporates a ground fault interrupter, which trips in less than 5 milliseconds when the current to the negative side of the power supply from the shield wire or from the water exceeds 1 mA. The electrode connects the diver's body to the shield wire. Finally, the connection between the controller and the passthrough cable has no locking arrangement, and may be disconnected with a straight pull.

The controller incorporates a manual on-off switch, the GFI circuitry, a GFI override switch, and indicating lights. A faulty underwater connector, shutting down the system, but resulting in no electrical shock to the diver commonly causes GFI trips. The GFI override function maybe used in the event that the system trips, but the diver judges that the danger due to loss of heat is greater than the electrical hazard. The controller also incorporates an "auto-latch" feature, which probes the circuit twice a minute, and applies power if it senses that a suit is connected. The auto-latch feature helps to reduce the effect of nuisance trips.

The controller applies power to the suit in pulses. Internal circuitry senses the voltage being supplied, and adjusts the pulse on-time to result in a fixed average heating rate of 260 watts, of which 11 watts are delivered to each hand.

#### **Controller Inspection**

Connect the controller to a passthrough cable and suit. Connect one glove on one sleeve, and a GFI test box to the other sleeve. Hang the garment ensemble freely from a hanger so it can cool itself. Connect the controller to a 15 Volt DC power supply or battery capable of supplying

20 amps. **Caution: Observe correct polarity. Incorrect polarity at the power supply will damage controller.**

- Testing Manual Power Switch

Turn power switch on. Observe that the green light on the controller comes on solid. Observe that the light on the GFI test box flashes.

- Testing Ground Fault Interrupter

Introduce a ground fault by pushing the ground fault switch on GFI test box for one second. Observe that the green controller light and the GFI test box light extinguish, indicating a trip.

- Testing Auto-Latch Circuit

Release the ground fault switch. Observe that power is automatically re-applied to the suit in 40 seconds or less.

- Testing GFI Override Feature

With the power switch on, turn the GFI Override switch on the controller. Observe that the red light comes on solid. Introduce a ground fault with the GFI test box as above. Observe that the power to the suit does not trip.

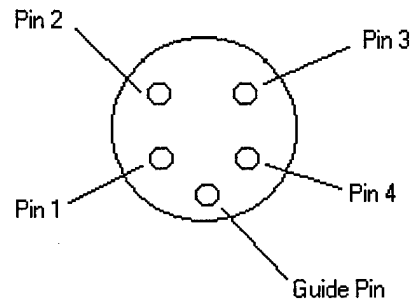
- Testing the Voltage Compensation Feature

The following assumes your power supply is capable of delivering a variable voltage. Apply 15 volts DC and switch the power to the suit on. Observe that the green light on the controller comes on solid and that the light on the GFI test box flashes. Reduce the voltage, observing that the light on the GFI test box stays on longer as the voltage is reduced. The GFI test box light should go solid on at about 12 volts. **Caution: Do not apply more than 22 volts to the system. Damage to the system may result. In addition, the AODC code referenced above does not allow the use of more than 22.8 volts DC for diver heating systems.**

### Inspection for Ground Faults, Wire Damage, and Garment Operation

Test suit, gloves, and dry suit passthrough cable for ground faults and wire damage after laundering and before drying. Connect gloves, electrode, and passthrough assembly. Immerse suit and gloves in tap water, taking care to submerge the suit, gloves, and the passthrough/ suit connectors, but not the large connector on the passthrough cable, and not the electrode band. Obtain a digital multimeter capable of

reading resistances in excess of 20 megaohms. Place one lead from the multimeter into the water surrounding the suit. Touch the other lead to the metal bands on each of the passthrough connector pins in turn. The meter should read open circuit on all four pins. Immerse the electrode armband into the water and touch the multimeter lead to each of the same connector pins in turn. The meter should read less than 5 megaohms when connected to pin 4 (see diagram below) and open circuit when connected to pins 1, 2, and 3.



Remove the multimeter lead from water and measure the resistance between pins 2 and 3. The multimeter should indicate less than 5 ohms. Measure the resistance between pins 1 and 2. The multimeter should indicate less than 5 ohms. Measure the resistance between pin 4 and pins 1, 2, and 3 in sequence. The multimeter should indicate open circuit.

Disconnect both gloves and measure the resistance between the pins on the glove connectors. The multimeter should indicate between 4 and 5 ohms.

Inspect the suit and gloves visually along the wire length for signs of wire damage such as cuts or abrasion of the wire jacket.

Reconnect the gloves and hang the ensemble freely from a hanger so it can cool itself. Connect the passthrough cable to a controller and a 15-volt DC power source capable of supplying 20 amps. Allow the garments to run for 5 minutes. Feel along the suit and glove wires and connectors with fingers to detect any hot spots. Observe that both gloves and all circuits in the suit are heating.

## LAUNDERING

Hand wash suit and gloves in warm water using ordinary laundry detergent. Hang to dry. After laundering, grease the rubber part of the pins on the multi-contact connectors lightly with silicone grease. Do not grease the single pin connectors.

## Donning Electric Garments

Wear the electric suit over socks. Lightweight long underwear or briefs are also recommended.

Apply electrolyte to the electrode foam. Slip the electrode band over upper arm with the wire pointing toward the shoulder. Ensure that the foam rests directly on the skin. Don the electric suit. The suit may be worn over lightweight long underwear and socks if desired. The electric suit should be large enough to allow the diver to bend without restriction, and yet not so large those electric wires are caused to bunch together in folds. Don gloves and connect. Don divers' insulating underwear. Pass single pin suit connectors at belly of electric suit through insulating underwear, separating the wire leads to avoid a hot spot. Don dry suit to waist. Connect male and female single pin connectors to mating connectors on the inside of passthrough cable. Arrange the glove sealing strips to run smoothly under dry suit cuff seals. Diver's wrists, dry suit cuff seals, and electric glove strips may be greased with silicone grease to ensure a better seal. Complete donning of dry suit and outer gloves in normal manner.

### **Warning:**

- Operate suit only in conjunction with Steadfast Controller equipped with a ground fault interruption (GFI) circuit.
- Do not dive suits without electric gloves connected.
- Do not use suit without electrode connected and properly in contact with user's skin.
- Do not use suit with sleeves rolled up or if wire is bunched together in any spot.
- Do not operate suit if the wire is damaged, or if the suit exhibits any ground fault or hot spot when inspected as described above.

Failure to operate suit in compliance with these instructions can lead to diver injury.

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